10/018382
3 Rec'd PCT/PTO 18 DEC 2001

GR 99 P 8083

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Description

Electromechanical connection between electronic circuit systems and substrates, and method for producing this connection

The present invention relates to an electromechanical connection between electronic circuit systems and substrates in accordance with the preamble of patent claim 1 and to a method for its production in accordance with patent claim 31.

In the context of the present invention, the term electronic circuit systems is understood as meaning solid-state circuit systems, in particular integrated semiconductor circuits. Specifically, the term system indicates, for example in an integrated semiconductor circuit, the semiconductor material body which holds the electronic functional circuit elements, such as transistors, diodes, capacitors, etc., and the metallic conductor tracks and connection elements which are situated on this body and connecting the functional circuit elements.

The connection elements may be flat applications of metal, known as pads, or spherical metallic elements, known as bumps.

In the context of the present invention, the term substrates is understood as meaning circuit boards, such as printed circuits or printed-circuit boards. Substrates of this type also have connection elements of the abovementioned type, generally in the form of pads.

It is known to produce electromechanical connections of

the type under discussion by means of an adhesive which

contains electrically conductive grains. An electro-mechanical connection of this type is explained below with reference to Fig. 1.

Fig. 1 diagrammatically depicts an electronic circuit system 10, for example an integrated semiconductor circuit, which is electrically and mechanically connected to a substrate 20, for example a printed-circuit board. Connection elements in the form of pads are present on the circuit system 10, and connection elements 21, which are likewise in the form of pads, are present on the substrate 20.

The circuit system 10 and the substrate 20 are connected to one another using the flip-chip technology in such a manner that the pads 11 and 21 come to lie facing one another, with an adhesive 24, which contains electrically conductive grains 22 and 23 and is indicated by dot-dashed lines, between them. The adhesive 24 may, for example, be a polymer, while the conductive grains may consist of silver.

In a connection of the abovementioned type, electrically conductive grains, which are in this case denoted by 22, come to lie in the lateral spaces between the pads 11 and 21, and conductive grains which are denoted by 23 come to lie in the vertical spaces between pads 11 and 21 which face one another.

Pressing the circuit system 10 and substrate 20 together ensures that the electrically conductive grains 23 between pads 11 and 21 which face one another come into electrically conductive contact with these pads, producing an electrical connection between circuit system 10 and substrate 20. By contrast, the electrically conductive grains 22 in the lateral spaces between pads 11 and 21 do not come into electrically conductive connection with the pads, so that in this respect there is no short-circuiting connection between pads. An

electrical connection of the type described is anisotropically conductive, in that an electrically

conductive connection is produced in the vertical direction by electrically conductive grains 22 between pads 11 and 21 which face one another, but is not produced in

the lateral direction by electrically conductive grains 22 in lateral spaces between pads 11 and 21.

To indicate that the electrically conductive grains 23 between pads 11 and 21 which face one another can be deformed during compression, they are diagrammatically indicated in an oval shape, while the grains 22 in the lateral spaces between pads 11 and 21 remain undeformed and are therefore diagrammatically indicated in the shape of a circle.

In the type of electromechanical connection described above, the following conditions have to be satisfied for reliable operation.

Firstly, the adhesive 24, during setting and when the circuit system 10 and substrate 20 are operating, has to develop sufficiently high shrinkage forces to ensure permanent compression and therefore a reliable mechanical connection between circuit system 10 and substrate 11. However, adhesives do not generally have good properties in terms of adhesion and resistance to moisture, and consequently a connection of this type is not sufficiently reliable. Particularly in the event of fluctuating thermal loads, high shear forces may arise in the adhesive join, with the result that the adhesive may break open and, as a result, the electrical connection through the electrically conductive grains 23 may be broken. Furthermore, moisture which penetrates into the join may, when heated, cause entire areas of the circuit system 10 to break away from the substrate 20. These drawbacks are offset by the advantage that adhesives do not need to be structured.

Secondly, the amount of electrically conductive grains

22, 23 in the adhesive 24 must be sufficiently large to

ensure that there is at least one electrically conductive grain 23 between pads 11, 21 which face one another, in order to guarantee an electrically conductive connection. On the other hand, the amount of these grains must not be so high that there is a risk of

electrical short circuits being caused by electrically conductive grains 22 in lateral spaces between pads 11, 21.

As the level of integration increases and therefore the electrically conductive structures become smaller, as do the distances between them on integrated semiconductor circuits and matching structures on substrates connected to the circuits, such as for example printed-circuit boards, the latter problem becomes increasingly important.

To counteract this problem, it is known from "Flip Chip Technologies" by John H. Lau, McGraw-Hill, 1996, pages 289-299, to use microcapsules which are embedded in an adhesive and comprise electrically conductive grains and a dielectric surrounding them, for example in the form of an insulating plastic. A microcapsule of this type comprising an electrically conductive grain 22-1 (or 23-1) and a dielectric 22-2 (or 23-2) surrounding it is illustrated on an enlarged scale in Fig. 2.

In an electromechanical connection using conductive grains surrounded by a dielectric in an adhesive also requires the circuit system 10 and the substrate 20 to be pressed together, as shown in Fig. 1. As a result of the pressure which is generated by this operation and the setting of the adhesive 24, the microcapsules 23-1, 23-2 between pads 11, 21 which face one another are compressed, with the result that the dielectric 23-2 is broken open and, as a result, an electrically conductive connection is formed via the electrically conductive grains 23-1. This state of affairs is diagrammatically illustrated in Fig. 3 in the form of a deformed microcapsule 23-1, 23-2 between two pads 11, 21.

Although in an electromechanical connection of this type produced by means of microcapsules of the type described above the problem of lateral electric short circuits via microcapsules 22-1, 22-2 situated in the lateral spaces between pads 11, 21 is virtually eliminated,

the problems described above in connection with the adhesive remain as before.

The present invention is based on the object of providing an electromechanical connection of the type under discussion which, even with fine electrically conductive structures on electronic circuit systems and substrates, is both mechanically and electrically stable and prevents electric short circuits.

With an electromechanical connection of the generic type, this object is achieved, according to the invention, by the measures given in the characterizing part of patent claim 1.

A method for producing an electromechanical connection according to the invention is characterized by the measures given in patent claim 31.

Refinements of the electromechanical connection according to the invention and of the method according to the invention form the subject matter of corresponding subclaims.

The invention is explained in more detail below on the basis of exemplary embodiments in conjunction with the figures of the drawing, in which:

Figures 1 to 3 show the known embodiments which have already been explained above, and

Fig. 4 shows a diagrammatic illustration, corresponding to that shown in Fig. 1, of an electromechanical connection in order to explain embodiments in accordance with the invention.

The essence of the invention is to be seen as residing in the fact that, in addition to a compressive connection to produce the electrical connection between an electronic circuit system and a

substrate, a metallic solder joint is produced at least at the locations of the electrical connections.

In Fig. 4, on the basis of which embodiments of the invention are explained, identical elements to those shown in Figures 1 to 3 are provided with identical reference symbols.

As has already been explained with reference to Fig. 1, the arrangement shown in Fig. 4 is likewise an electromechanical connection between an electronic circuit system 10, for example an integrated semiconductor circuit system, and a substrate 20, for example an electrical printed-circuit board. Electronic circuit system 10 and substrate 20 once again have the connection elements in the form of pads 11 and 21.

The purely mechanical connection takes place by means of the adhesive 24 which is indicated by dot-dashed lines, for example a polymer, in which, however, unlike in the known embodiment shown in Fig. 1, it is not purely metallic electrically conductive particles 22, 23, but rather microcapsules 22-1, 22-2, 23-1, 23-2 which are suitable for a soldering operation that are embedded. Embodiments of these microcapsules are explained in more detail below.

It should be noted that the invention is not restricted to embodiments used with an adhesive 24 to produce the purely mechanical connection between electronic circuit system 10 and substrate 20. Embodiments in which a connection is produced by means of a soldering operation without adhesive, which is described in even more detail below, are also possible. This can take place by means of pads 11, 21 which are inactive for the intended

"inactivity" means that pads of this type are not electrically connected to electronic functional elements in electronic circuit system 10 or on or in substrate 20.

electronic operation of electric circuit system 10 and substrate. In this context, the term

A first embodiment of a soldered joint in the context of the invention is explained below.

In this embodiment, the microcapsules comprise electrically conductive grains 22-1, 23-1 which are covered with a dielectric 22-2, 23-2 and may consist of a metal selected from the group consisting of copper, nickel, silver, gold, a solderable metal alloy or an insulator, for example tin oxide, which is covered with an electrically conductive metal, for example silver. The way in which microcapsules of the latter type can be produced is known, for example, from "JOURNAL OF MATERIALS SCIENCE" 28 (1993), pages 5207-5210.

The dielectric 22-2, 23-2 used may be an insulating enamel, which may also act as a soldering flux.

For the soldering operation, layers of solder 25, 27, for which a metal selected from the group consisting of tin, indium, gallium, or a metal alloy with a low melting point may be used, are provided on the pads 11, 21 in order to produce the electrically conductive connection between electronic circuit system 10 and substrate 20. The layers of solder 25, 27 are preferably produced by selective electroless deposition on the pad surfaces, so that it is possible to produce sufficiently planar surfaces.

In accordance with the method according to the invention, microcapsules 22-1, 22-2, 23-1, 23-2, which are embedded in the adhesive 24 or a polymer film, which is not specifically shown in Fig. 4, are introduced between the electronic circuit system 10 and the substrate 20, and they are compressed together under such a force that the dielectric 23-2 of microcapsules 23-1, 23-2 situated

which face one another is broken open. After the compression, the arrangement is heated to a temperature which lies above the melting point of the solder material of the layers of solder 25, 27. In the process, the molten solder comes into contact with material of the electrically conductive grains 23-1 of the

between pads 11, 21

microcapsules 23-1, 23-2, and a metallic bond with good electrical conductivity is produced.

Microcapsules 22-1, 22—2 in lateral spaces between pads 11, 21 remain unaffected by the compression operation and therefore their dielectric 22-2 remains intact, with the result that lateral short circuits are prevented. Therefore, the electromechanical connection according to the invention is anisotropically conductive in the sense explained above.

It is particularly advantageous if a diffusion-soldering method is used for the soldering. In this method, a metallic bond which is able to withstand high temperature is produced using a low-melting solder as a result of the solder metal forming an intermetallic phase, which is able to withstand high temperatures and is very mechanically stable, with high-melting metals which are to be connected. In the process, the low-melting solder metal is completely transformed, i.e. passes completely into the intermetallic phase. A soldering method of this type is known per se, for example from US-A 5 053 195.

For this method, the layers of solder 25, 27 have a thickness of the order of magnitude of 10 μm, preferably of less than 10 μm. They consist, for example, of tin. The electrically conductive grains 23-1 or the metallic layers of grains in the form of metallized insulators, and if appropriate the pads 11, 21, consist, for example, of copper or nickel. When contact is made between the metal of the grains during the diffusion-soldering method, the tin is completely transformed into intermetallic phases, which are denoted by 26, 28 in Fig. 4. As has already been explained, the joint which is formed in the process has a significantly higher melting

metal and better mechanical properties, such as high tensile strength and freedom from creep.

In a development of the invention, it is essential in a soldering process of this type that a single

point than the solder

layer of microcapsules is situated between the pads 11, 21 and the pad surfaces are sufficiently planar. Then, all the microcapsules 23-1, 23-2 situated between pads 11, 21 which face one another are compressed, so that their electrically conductive grains 23-2 or their electrically conductive parts come into contact with the solder metal.

The single-layer structure can be produced particularly successfully if - as stated above - the microcapsules 22-1, 22-2, 23-1, 23-2 are previously embedded in a polymer film. The way in which films with embedded microcapsules of this type can be built up and produced in detail is known per se, for example from 1992 "IEEE", pages 473 to 480 and 487 to 491. A film of this type ensures the lateral insulation of the microcapsules 22-1, 22-2, 23-1, 23-2 and can act as a spacer. Shaped parts which match the surfaces which are to be connected can be produced. The adhesive 24 can then be dispensed with, if appropriate.

It should be mentioned once again that the configuration described above is not specifically illustrated in Fig. 4. Also, soldered joints between pads 11, 21 which are inactive in the sense mentioned above and microcapsules 23-1, 23-2 without any adhesive 24 being present are not specifically illustrated in Fig. 4. However, in Fig. 4 it would be possible, for example, for the two pads 11, 21 shown on the right-hand side of the drawing to be regarded as "inactive" pads and for the two pads 11, 21 situated on the left-hand side of the drawing to be regarded as "active" pads.

In a further embodiment of the invention, it is possible to use microcapsules 22-1, 22-2, 23-1, 23-2 which at

least in part consist of a solder metal.

According to one variant of this embodiment, the electrically conductive grains 22-1, 23-1 consist entirely of solder metal, in which case a metal selected from the group consisting of tin, indium, gallium or a soft-solder alloy can be used as solder metal.

In this case, a solderable metal which may be a metal selected from the group consisting of copper, nickel, silver or gold is used as material for the pads 11, 21 of the electronic circuit system 10 and substrate 20.

In this embodiment too, the electrically conductive grains 22-1, 23-1 of the microcapsules 22-1, 22-2, 23-1, 23-2 are surrounded by a dielectric 22-2, 23-2 in the form of a layer of insulating enamel. As well as its insulating action in the lateral direction, which has been explained above, this layer of insulating enamel additionally prevents in particular electrically conductive grains 22-1 in the lateral spaces between pads 11, 21 of electronic circuit system 10 and substrate 20 from flowing together when heated during the soldering process and therefore prevents short circuits in the lateral direction.

Since the solder material of the electrically conductive grains 23-1, 23-2 of the microcapsules 22-1, 22-2, 23-1, 23-2 becomes liquid during the soldering process, and therefore the layer of insulating enamel breaks more easily, the pressure required to break open this layer between pads 11, 21 which face one another is not as high as in the first embodiment of microcapsules which was explained above. When the solder material makes contact with the material of the pads 11, 21, the soldered joint is formed, and therefore electrical and mechanical contact is made.

Since the microcapsules 22-1, 22-2 in the lateral spaces between pads are not compressed, their layers of insulating enamel 22-2 remain intact. When using an adhesive 24, these microcapsules are held together by this adhesive or when embedded in a polymer film in the

sense explained above, and cannot flow out.

Therefore, in this embodiment too, the diffusion-soldering method explained above is particularly advantageous. The electrically conductive grains 22-1, 23-1 of the microcapsules

22-1, 22-2, 23-1, 23-2 may, for example, consist of tin and the pads 11, 21 of electronic circuit system 10 and substrate 20 may consist of copper or nickel. If the electrically conductive grains of the microcapsules have a diameter of less than 10 μm, the tin is completely transformed into the intermetallic phase 26, 28 when contact is made between the solder metal and the pad metal. In turn, an electromechanical connection with a melting point which is significantly higher than that of the solder metal and therefore excellent mechanical properties, such a high tensile strength and freedom from creep, is formed.

Electrically conductive grains with a small diameter of the order of magnitude of 10 μm and preferably less than 10 μm are advantageous for a number of reasons.

Firstly, the thicker the electrically conductive grains, the longer the process of chemical transformation takes during the diffusion soldering. For example, with a diameter of 40 μm the reaction takes over half an hour. With diameters of less than 10 μm, the reaction time is of the order of magnitude of minutes.

Secondly, the pads 11, 21 have to be sufficiently thick to be able to provide sufficient metal for the transformation reaction. When using electrically conductive grains having the preferred diameters, there is relatively little solder metal available, so that correspondingly a small amount of pad metal needs to be available for complete transformation.

Thirdly, small diameters of the electrically conductive grains are of benefit to finely structured contacts, which is advantageous in particular for integrated

semiconductor circuits with a high level of integration.

Fourthly, the diameter of the electrically conductive grains determines the thickness of the soldered joint. Thin soldered joints have a better

fracture behavior. With a thickness of less than 5 μm, the joint has a elastic action when bent, whereas if its thickness is greater than 10 μm it becomes brittle, so that stress cracks may easily form.

As a modification to the embodiment described above, the electrically conductive grains 22-1, 22-2 of the microcapsules 22-1, 22-2, 23-1, 23-2 may not consist entirely of solder metal, but rather may consist of a metal core which is covered with solder metal. This may, for example, be a copper core which is covered with a layer of tine solder. If the tin solder is deposited electrolessly in a tin exchange bath, the top layer of the copper core is replaced by a correspondingly thin layer of tin. A typical thickness of the layer of tin is of the order of magnitude of 200 nm.

The use of electrically conductive grains of this type, including for use in the mechanical and electrical connection of objects, is known per se, for example from 1996 "Electronic Components and Technology Conference", pages 565-570, which describes an electrically conductive adhesive material which comprises a conductive filler powder, which is covered with a metal with a low melting point (solder metal), a thermoplastic polymer and further minor organic additives. The filler grains are coated with the metal of a low melting point which, when producing a connection between objects, is melted in order to produce a metallurgical bond between adjacent filler grains and between filler grains and metallic connection elements on the objects which are to be connected. A connection of this type corresponds to the arrangement shown in Fig. 1. In this case too, the problems explained above with regard to the adhesive formed by the polymer and with regard to the amount of

electrically conductive grains used, are encountered.

As in the two embodiments explained above, electrically conductive grains 22-1, 22-2 of this type are covered with a dielectric 22-2, 23-2 in the form of a layer of insulating enamel. It should be noted that the fact that the electrically conductive grains may for their part be of two-part form is not specifically illustrated in Figures 2 to 4.

One advantage of electrically conductive grains 22-1, 23-1 in the form of metal cores which are covered with solder metal is that the soldering process, which is once again preferably in the form of the diffusion-soldering process, takes place very quickly and precisely, on account of the overall very thin layer of solder. A further advantage is that even in microcapsules 22-1, 22-2 in the lateral spaces between pads 11, 21, which are therefore not in contact with pads 11, 21, the solder reacts with the core metal and is transformed into an intermetallic phase. Therefore, microcapsules of this type, too, are firmly stable at temperatures which lie well above the melting point of the solder, since they can no longer become liquid.

Furthermore, on account of the low thickness of the layers of solder of the electrically conductive grains and the resultant relatively small quantity of solder metal, the thickness of the pads 11, 21 can be reduced, since a correspondingly small quantity of pad material is required for complete transformation of the quantity of solder. A further reason for using layers of solder of small thickness is that it is no longer necessary for pads to be raised, since the solder of the electrical conductive grains can no longer "run out" when the layer of insulating enamel breaks open, since the low layer thickness means that the solder adheres to the surface of

the metal core, providing good wetting of the latter.

For the above reasons, in all the microcapsules 22-1, 22-2, 23-1, 23-2, both those in lateral spaces between pads 11, 21 and those between pads which face one another, it is no longer possible for any liquid solder, which leads to short circuits, to form at operating temperatures of the arrangement.

Electromechanical contact with the pads 11, 21 results from the reaction of the solder of the electrically conductive grains 23-1, 23-2 with the metal of the pads 11, 21.

A further advantage in particular in the embodiments with electrical conductive grains 22-1, 23-1 comprising metal other than solder metal and layers of solder 25, 27 on the pads 11, 21, as well as electrically conductive grains comprising metal cores covered with a layer of solder, is that it is possible to produce particularly thin solder layers, which can be controlled accurately, during the diffusion-soldering method, in the form of intermetallic phases 26, 28.

In the embodiments described above, the microcapsules 22-1, 22-2, 23-1, 23-2, apart from the variant involving embedding in a polymer film, can be processed with an insulating liquid, which may be the abovementioned adhesive 24 or a flux, to form a paste. In the case of the adhesive, it is possible to combine the advantages of an adhesive bond and of a soldered joint. This adhesive bond ensures additional mechanical stability, and the soldered joint ensures reliable electrical connection.

To summarize, it should be pointed out once again that, according to the invention, it is possible to achieve a creep-resistant connection, since during the preferred diffusion soldering the solder material, as a thin layer on the microcapsules or the connection elements on the electronic circuit system and the substrate, is completely changed into the intermetallic phase, i.e. no residues of solder material remain. Furthermore, the thin layers of solder material ensure that the soldering process takes place relatively quickly.

Furthermore, the large quantity of microcapsules which is possible even with small connection element structures means that reliable electrical connection in combination with good thermal conduction and – on account of the mechanical soldered joint via the soldered microcapsules – a significantly more reliable mechanical connection compared to a pure adhesive bond is ensured.

Finally, high thermal stability of electromechanical connection is also ensured, since the overall connection operation can be designed in such a way that no residues, such as for example insulating residues of metal oxides, glass or ceramic or binder, remain in the connection.